High Contrast and High Damage threshold XUV/Visible Dichroic Mirror

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Abstracts: *A high-contrast XUV/visible dichroic mirror has been developed for beam separating and combining of high-order harmonics light and its pump-beam. This grazing incident angle AR coating based dichroic mirror has p-polarization reflectivity more than 40% at XUV region and less than 1% at 800 nm. This contrast is comparable with conventional method such as metal thin-film filters and Brewster's angle based beam separators, and the dichroic mirror, in principal, has higher damage threshold than the others. This easy-customized optical components will be useful for all high-order harmonic light sources including VUV and soft x-ray region.*

High-order harmonics (HH) is a powerful light source for many kinds of research applications, such as spectroscopy, microscopy, and ultrafast dynamics measurements in VUV, XUV and soft x-ray region. The system is mainly constructed with pump laser, high-order generation, spectral filter, beam steering mirror, focusing mirror and spectrometer. In addition, some systems have an interaction chamber. In this chamber, focused HH beam is interacted with many kinds of targets, for example gasses, liquids, solid surface, thin film, particle and clusters.

To obtain small signal from interaction between HH beam and target materials, to increase S/N ratio is one of the most important technique in this field, and considering low-conversion efficiency from pump-beam to HH beam, high-performance XUV filters have been required. For a long time, metal thin-film filters were only-one solution in this field [1], but in 2004, Brewster's angle beam separator is designed and demonstrated [2-4]. This beam separator are large size, high-contrast and higher damage threshold comparing with those of metal thin-film filters and have been used in many HH beam lines. However, because of recent developments of high-power compact HH source systems, much higher irradiation tolerance filters are required. The beam separator is typically based on Si or SiC plate, and their light absorption is sometime cause of shape deformation or damage.

In this paper we propose and demonstrate a dichroic mirror for XUV and visible laser beam. This mirror is based on AR coating on fused silica substrate and no absorption for visible light, and the coating is corresponding to high-intense femtosecond laser pulses. In addition, XUV light is total reflected from surface layer of coating. This technology have been already proposed in academic field [5], but limited only academic demonstrations. We NTT-AT have developed them as commercial products both standard and customized model. Note that this technology applied not only XUV region but also for VUV or soft x-ray region.

Calculated reflectivity profiles of our standard dichroic mirror P/N DM-13.5/800-2002 at NIR region and XUV region are shown in figure 1 (a) and (b), respectively. The calculations are assumed grazing incident angle of 12 degrees and p-polarization. The results shows that reflectivity of less than 1% at NIR region and more than 40% at XUV region are obtained. Note that inter-layer roughness and surface roughness are not included in these calculations, but the measured reflectivity profiles are almost as same as calculated values.

To understanding detail properties of our dichroic mirror, we show NIR reflectivity depended on polarization and incident angle in Fig. 2 (a) and (b), respectively. The results show that the dichroic mirror is high dependence on polarization and broadband capability for incident angle.

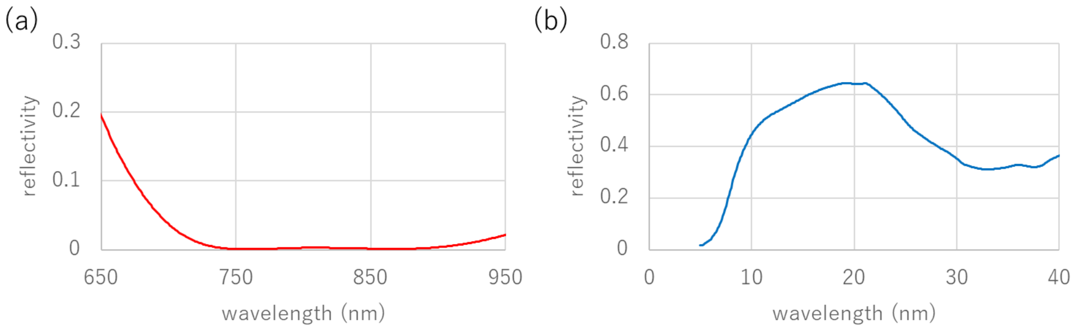

Fig. 1 Calculated reflectivity of DM-13.5/800-2005, (a) visible region and (b) XUV region. Assuming grazing incident angle of 12 deg., and p-polarization.

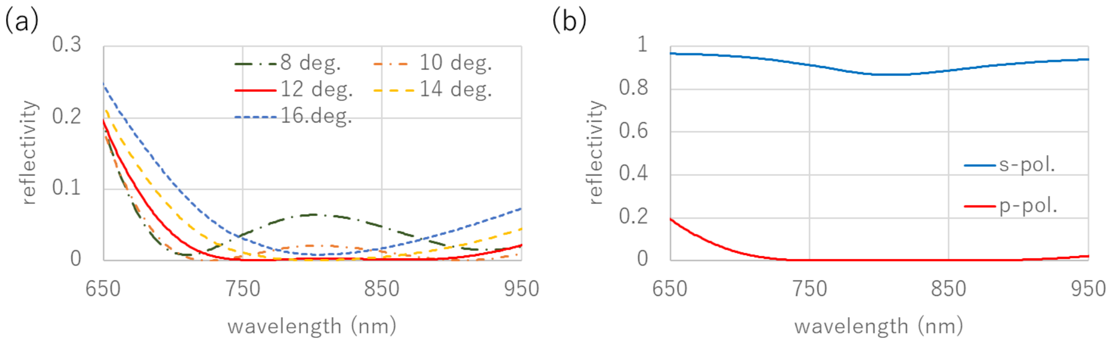

Fig. 2 (a) incident angle dependence and (b) polarization dependence of DM-13.5/800-2005.

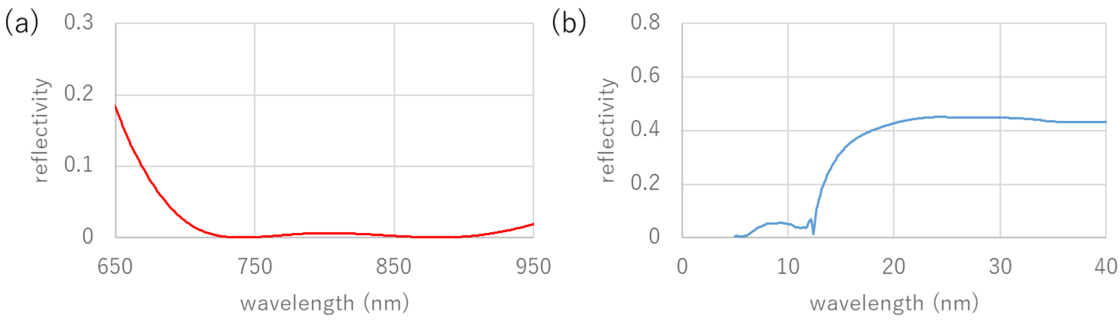

Fig. 3 Calculated reflectivity of DM-29.6/800-2005, (a) visible region and (b) XUV region. Assuming grazing incident angle of 12 deg., and p-polarization.

In addition, reflectivity profiles of another standard P/N DM-29.6/800-2002 are shown in Fig. 3. Specifications of standard dichroic mirrors include outer dimensions are shown in table 1.

In table 2, we show capability of customized dichroic mirror. The dichroic mirrors are based on dielectric multilayer AR coating technology, thus, easily designed depend on requirement, such as target XUV wavelength visible/NIR wavelength, and incident angle. For example, higher XUV reflectivity will be obtained at smaller grazing incident angle, but visible/NIR reflectivity also will become higher at smaller grazing incident angle. It is trade off and depend on customers' requirements. In Fig. 4 (a) and (b), we show customized dichroic mirror calculations as examples. As shown in these figures, they will work not only for XUV region but also VUV and soft x-ray region.

Table 1. Specification of standard dichroic mirrors

P/N	DM-13.5/800-2002	DM-29.6/800-2002
AOI	78 deg	
polarization	p	
NIR reflectivity	~2% @800 nm+/- 50 nm	~2% @800 nm+/- 50 nm
XUV reflectivity	~60% @20 nm	~45% @30 nm
Coating	Dielectric AR	
Substrate material	Fused silica	
Dimensions	2” dia. x 0.2" thick	

Table 2. Specifications of customized dichroic mirror

AOI	75 deg. - 87 deg.
polarization	p, s
target AR wavelength	400 nm, 515 nm, 800 nm, 1030 nm, etc.
HR wavelength	3-5 nm, 13.5 nm, 30 nm, 60 nm, 110 nm, etc.
Coating	Dielectric AR
Substrate material	Fused silica
Dimensions	Round (1" dia. - 4" dia.) rectangler (~100 mm length)

Although there are no experimental data of damage thresholds, in principal, damage threshold of this dichroic mirror is higher than that of conventional filter/beam separators. It is because all coating materials have no absorption for visible/NIR wavelength and substrate quality is high enough for high-intensity beam irradiation.

In conclusion, this dichroic mirrors have many advantages comparing with conventional filters and beam separators, high optical performance, easy customized, and high damage threshold. This new optics will be used for all high-order harmonics light source for wide-range wavelength region. Especially, it will be powerful tool for high intensity high-order harmonics sources.

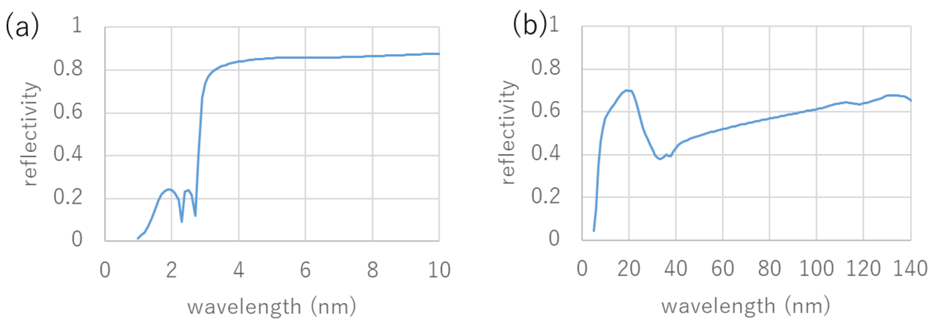

Fig. 4 Customized dichroic mirror example. (a) Assuming gazing incident angle is 3 deg., and calculated reflectivity at 1030 nm is <20%. (b) Assuming grazing incident angle is 10 deg., and calculated reflectivity at 345 nm is <1%.

[1] F. R. Powell et. al., Opt. Eng. 26, 614 (1990).
[2] E. J. Takahashi et. al., Opt. Lett. 29, 507 (2004).
[3] Y. Nagata et. al., Opt. Lett. 31, 1316 (2006).
[4] S. Ichimaru et. al., Appl. Opt. 55, 984 (2016).
[5] H. Carstens et. al., Optica 3, 366 (2016).